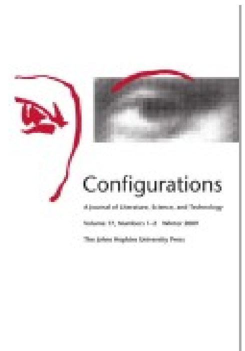
The Image and Imagination of the Fourth Dimension in Twentieth-Century Art and Culture

Linda Dalrymple Henderson



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The Image and Imagination of the Fourth Dimension in Twentieth-Century Art and Culture

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Abstract:

One of the most important stimuli for the imaginations of modern artists in the twentieth century was the concept of a higher, unseen fourth dimension of space. An outgrowth of the *n*-dimensional geometries developed in the nineteenth century, the concept predated the definition of time as the fourth dimension by Minkowski and Einstein in relativity theory. Only the popularization of relativity theory after 1919 brought an end to the widespread public fascination with the supra-sensible fourth dimension between the 1880s and 1920s. Initially popularized by figures such as E. A. Abbott, Charles Howard Hinton, Claude Bragdon, and P. D. Ouspensky (as well as science-fiction writers), the fourth dimension was a multivalent term with associations ranging from science, including X-rays and the ether of space, to idealist philosophy and mystical "cosmic consciousness." This essay focuses on the differing approaches to higher spatial dimensions in the cubism of Pablo Picasso and Juan Gris, the suprematism of Kazimir Malevich, and *The Large Glass* project of Marcel Duchamp in the early twentieth century. It concludes by examining contemporary artist Tony Robbin's thirty-year engagement with the mathematics of four-dimensional geometry and computer graphics, as well as his current work with knot theorist Scott Carter.

In the wake of a short article on the four-dimensional hypercube titled "Visualizing Hyperspace," published in the March 1939 issue

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of *Scientific American*, the journal's editors found it necessary to respond in September 1939:

> From time to time . . . the editors have received inquiries from puzzled readers who appear to be confused about a variety of questions suggested by this article. Is not time the fourth dimension? How do mathematicians know that there are more than the three dimensions with which we are all daily familiar? . . . First, regarding time as the fourth dimension: True, time does figure in the so-called "space-time continuum," but not as an extra dimension of *space*.
>
> Next, how do they know there are extra dimensions of space? They don't! They play with them, however, just as if they did exist. . . . The mathematician is a whimsical fellow who deliberately enjoys creating a make-believe and then proceeding to show what would be the case if it were true. . . .
>
> What probably confuses the puzzled non-mathematician is the fact that the mathematician uses for his excursions into the imaginary the same word he uses in connection with something he and all the rest of us know to exist; that is, "dimensions." If he would call them something else the confusion would promptly end for most of us.[1]

The critical role of the imagination in mathematics and geometry has long been acknowledged and given more serious discussion than in this description of mathematicians as "whimsical fellow[s]." In the twentieth century, popular books such as Edward Kasner and James Newman's *Mathematics and the Imagination* of 1940 and David Hilbert and S. Cohn-Vossen's *Geometry and the Imagination* of 1952 have made that connection apparent for the lay public. Hilbert emphasized the importance of a specifically visual component of the imagination, declaring in his introduction: "With the aid of visual imagination, we can illuminate the manifold facts and problems of geometry, and beyond this, it is possible in many cases to depict the geometric outline of the methods of investigation and proof."[2] The beautiful drawings in Hilbert's books certainly stimulated the creative imaginations of a number of artists who used the book, including sculptor Mark di Suvero and members of the Park Place Gallery, who responded to his sections on topology and "Polyhedra in Three and Four Dimensions."[3] In a similar way, H. S. M. Coxeter's

1. A. G. Ingalls, "Hypergeometry and Hyperperplexity," *Scientific American* 161 (1939): 131. For the essay in question, see Ralph Milne Farley, "Visualizing Hyperspace," *Scientific American* 160 (1939): 148–149.

2. David Hilbert, "Introduction" to D. Hilbert and S. Cohn-Vossen, *Geometry and the Imagination*, trans. P. Nemenyi (New York: Chelsea Publishing, 1952), p. iii.

3. See ibid., secs. 23, 44–51 (chap. 6). Di Suvero noted his interest in the book in a telephone interview with the author on May 2, 2002. On the Park Place Gallery artists

1963 book, *Regular Polytopes*, served as a vital inspiration for painter Tony Robbin as he began to explore four-dimensional geometry during the early 1970s. Coxeter, noting that while "we can never fully comprehend" figures in four or more dimensions," had declared: "In attempting to do so, however, we seem to peep through a chink in the wall of our physical limitations, into a new world of dazzling beauty."[4]

Indeed, it was not simply geometry, but specifically the nineteenth-century field of *n*-dimensional geometry and the concept of a possible fourth spatial dimension that emerged from it in the 1870s that proved crucial to the imaginations of twentieth-century artists. From the 1880s to the 1920s, popular fascination with an invisible, higher dimension of space—of which our familiar world might be only a section or shadow—is readily apparent in the vast number of articles and the books such as architect Claude Bragdon's *A Primer of Higher Space (The Fourth Dimension)* (1913) published on the topic.[5] Two plates from Bragdon's book are useful in setting forth two of the basic ways of conceptualizing a higher spatial dimension: the generation of the next higher-dimensional form by motion through space (fig. 1), and sectioning or slicing (fig. 2). In both approaches, reasoning by analogy to the relationship of two to three dimensions is central to imagining the transition from three to four dimensions.

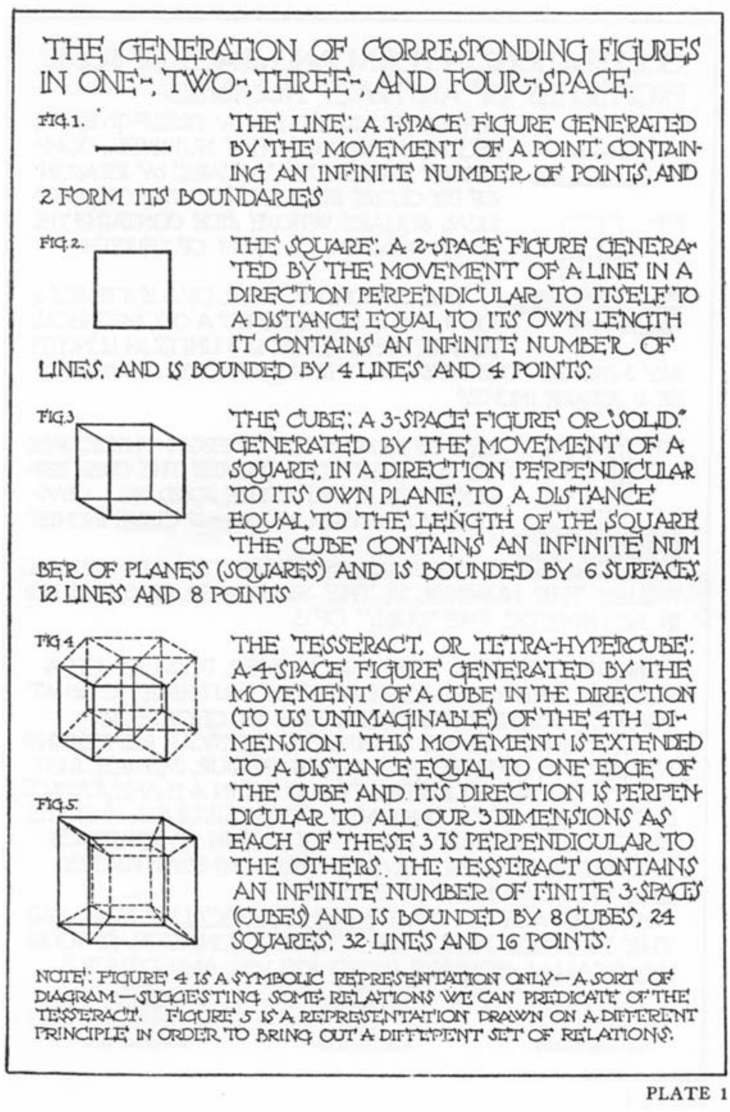
Just as Bragdon's beautiful hand-lettered plates provide a time capsule of approaches to the fourth dimension in 1913, the 1910 book, *The Fourth Dimension Simply Explained*, collected the winning essays in a 1909 contest sponsored by *Scientific American* on the topic, "What Is the Fourth Dimension?"[6] Virtually all of the *Scientific American* essayists in 1909 treated the fourth dimension as a spatial phenomenon, because the widespread popularization of Einstein's special and general theories of relativity (1905, 1916) would begin only in 1919 with the solar eclipse that established em-

and their interest in topology and the fourth dimension, see Linda Dalrymple Henderson, "Park Place: Its Art and History," in *Reimagining Space: The Park Place Gallery in 1960s New York* (Austin: Blanton Museum of Art, University of Texas, 2008), pp. 8–11, 14–15, 20–24.

4. H. S. M. Coxeter, *Regular Polytopes*, 2nd ed. (1963; reprint, New York: Dover Publications, 1973), p. vi.

5. See Linda Dalrymple Henderson, *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* (1983; new ed., Cambridge, MA: MIT Press, 2010), chap. 1, as well as appendix B for a sampling of popular articles; see also Claude Bragdon, *A Primer of Higher Space (The Fourth Dimension)* (Rochester, NY: Manas Press, 1913).

6. See Henry P. Manning, ed., *The Fourth Dimension Simply Explained* (1910; reprint, New York: Dover Publications, 1960).



THE GENERATION OF CORRESPONDING FIGURES IN ONE-, TWO-, THREE-, AND FOUR-SPACE.

FIG. 1. THE LINE: A 1-SPACE FIGURE GENERATED BY THE MOVEMENT OF A POINT; CONTAINING AN INFINITE NUMBER OF POINTS, AND 2 FORM ITS BOUNDARIES

FIG. 2. THE SQUARE: A 2-SPACE FIGURE GENERATED BY THE MOVEMENT OF A LINE IN A DIRECTION PERPENDICULAR TO ITSELF TO A DISTANCE EQUAL TO ITS OWN LENGTH IT CONTAINS AN INFINITE NUMBER OF LINES, AND IS BOUNDED BY 4 LINES AND 4 POINTS.

FIG. 3 THE CUBE: A 3-SPACE FIGURE OR "SOLID." GENERATED BY THE MOVEMENT OF A SQUARE, IN A DIRECTION PERPENDICULAR TO ITS OWN PLANE, TO A DISTANCE EQUAL TO THE LENGTH OF THE SQUARE THE CUBE CONTAINS AN INFINITE NUMBER OF PLANES (SQUARES) AND IS BOUNDED BY 6 SURFACES 12 LINES AND 8 POINTS

FIG. 4 THE TESSERACT, OR TETRA-HYPERCUBE: A 4-SPACE FIGURE GENERATED BY THE MOVEMENT OF A CUBE IN THE DIRECTION (TO US UNIMAGINABLE) OF THE 4TH DIMENSION. THIS MOVEMENT IS EXTENDED TO A DISTANCE EQUAL TO ONE EDGE OF THE CUBE AND ITS DIRECTION IS PERPENDICULAR TO ALL OUR 3 DIMENSIONS AS EACH OF THESE 3 IS PERPENDICULAR TO THE OTHERS. THE TESSERACT CONTAINS AN INFINITE NUMBER OF FINITE 3-SPACES (CUBES) AND IS BOUNDED BY 8 CUBES, 24 SQUARES, 32 LINES AND 16 POINTS.

FIG. 5.

NOTE: FIGURE 4 IS A SYMBOLIC REPRESENTATION ONLY—A SORT OF DIAGRAM—SUGGESTING SOME RELATIONS WE CAN PREDICATE OF THE TESSERACT. FIGURE 5 IS A REPRESENTATION DRAWN ON A DIFFERENT PRINCIPLE IN ORDER TO BRING OUT A DIFFERENT SET OF RELATIONS.

PLATE 1

Figure 1. "The Generation of Corresponding Figures in One-, Two-, Three-, and Four-Space." (Source: Claude Bragdon, *A Primer of Higher Space [The Fourth Dimension]* [Rochester, NY, 1913], pl. 1).

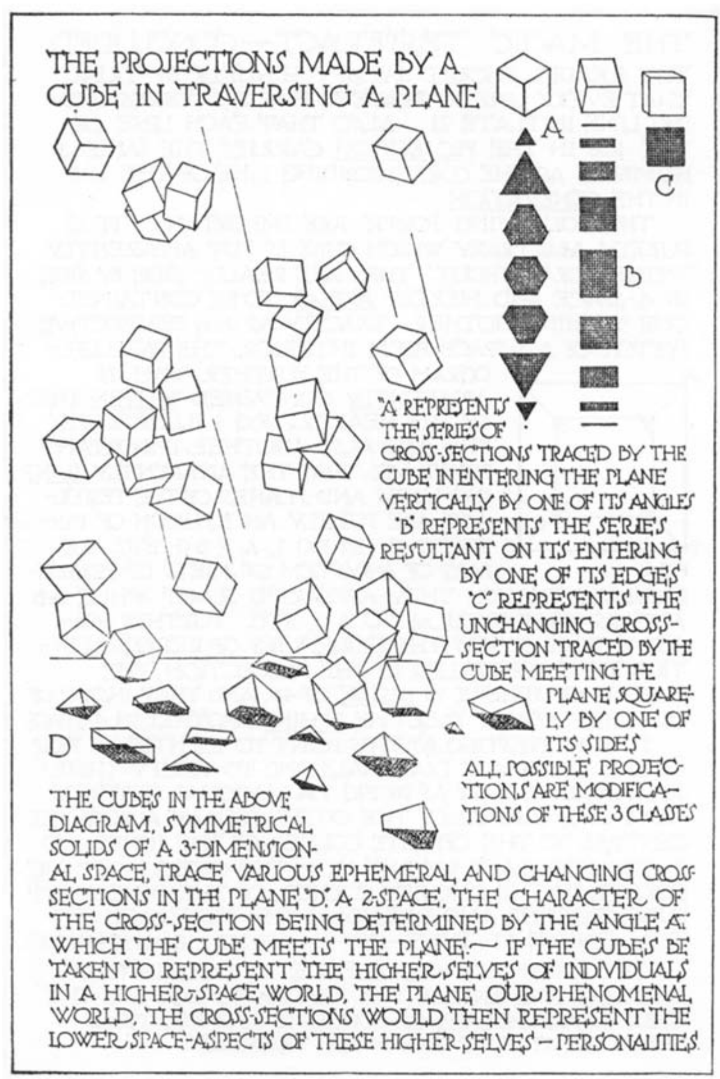


PLATE 30

Figure 2. "The Projections Made by a Cube Traversing a Plane." (Source: Claude Bragdon, *A Primer of Higher Space [The Fourth Dimension]* [Rochester, NY, 1913], pl. 30).

pirically the curvature of light that Einstein's theory had predicted.[7] It was little wonder, then, that in 1939, *Scientific American* readers were confused, since during the course of the 1920s, Einstein and mathematician Hermann Minkowski's earlier incorporation of time into the four-dimensional space-time continuum had gradually overshadowed cultural memories of the geometrical, spatial fourth dimension. During the 1930s through the 1950s, in fact, the fourth dimension of space essentially went underground, staying alive in nonmathematical culture primarily in science-fiction writing and in the mystical, philosophical literature that had developed around the idea.[8]

Mathematicians, of course, continued to study four-dimensional geometry, but even Kasner and Newman recognized the need to explain the idea to a 1940s audience in a chapter of *Mathematics and the Imagination* on "Assorted Geometries—Plane and Fancy." "Physicists may consider time to be the fourth dimension, but not the mathematician," they assert at the start of their explication of the concept. While their discussion focuses on the geometrical properties of four-dimensional objects and the analogies by which we can reason about them, their conclusion takes the idea well beyond the realm of geometry to point out its larger significance in the history of human thought: "No concept that has come out of our heads or pens marked a greater forward step in our thinking, no idea of religion, philosophy, or science broke more sharply with tradition and commonly accepted knowledge, than the idea of a fourth dimension."[9]

From its first popularization in English theologian E. A. Abbott's *Flatland: A Romance of Many Dimensions by a Square* of 1884, the fourth dimension had been linked to the enlarging or freeing of thought and imagination. Abbott dedicated his cautionary tale about a two-dimensional world oblivious of the larger three-dimensional space in which it existed "To the Inhabitants of Space IN GENERAL," whom he hoped would "aspire yet higher and higher To the secrets of FOUR FIVE OR EVEN Six Dimensions Thereby contributing To the Enlargement of THE IMAGINATION."[10] This theme would be-

7. On Einstein's theories and their reception, see, for example, Helge Kragh, *Quantum Generations: A History of Physics in the Twentieth Century* (Princeton, NJ: Princeton University Press, 1999).

8. For this history, see Henderson, "Reintroduction: The Fourth Dimension Through the Twentieth Century," in *Fourth Dimension* (above, n. 5).

9. Edward Kasner and James Newman, *Mathematics and the Imagination* (New York: Simon & Schuster, 1940), pp. 119, 131.

10. Edwin A. Abbott, *Flatland: A Romance of Many Dimensions by a Square* (Oxford: Basil Blackwell, 1950).

come a leitmotif of literature on the fourth dimension both in the context of mathematics and as it quickly acquired broader philosophical implications. As Casius Keyser wrote in a 1906 essay in *The Monist* titled “Mathematical Emancipations”: “The hyper-dimensional worlds that man’s reason has already created, his imagination may yet be able to depict and illuminate. . . . It is by creation of hyperspaces that the rational spirit secures release from limitation. In them it lives ever joyously, sustained by an unfailing sense of infinite freedom.”[11] Citing Keyser, H. P. Manning, in his 1914 textbook *Geometry of Four Dimensions*, argued that the “synthetic” study of the “forms and properties” of four-dimensional figures so “that it is almost as if we could see them” results in “greatly increas[ing] our power of intuition and our imagination.”[12]

The figure who definitively extended the fourth dimension beyond its mathematical roots, while maintaining its geometrical core meaning, was the Englishman Charles Howard Hinton. In his books *A New Era of Thought* (1888) and *The Fourth Dimension* (1904), Hinton developed the philosophical implications of four-dimensional space and secured its place in late nineteenth- and early twentieth-century culture. Hinton’s “hyperspace philosophy” was an idealist worldview based on his belief that by developing an intuitive apprehension of four-dimensional space, individuals would gain access to true reality and hence resolve the problems of the materialist three-dimensional world. According to Hinton,

> [w]hen the faculty is acquired—or rather when it is brought into consciousness, for it exists in everyone in imperfect form—a new horizon opens. The mind acquires a development of power, and in this use of ampler space as a mode of thought, a path is opened by using that very truth which, when first stated by Kant, seemed to close the mind within such fast limits. . . . But space is not limited as we first think.[13]

Hinton’s method for “educating the space sense” of his readers was a set of exercises to be carried out with a block of multicolored cubes, such as those pictured in various colors on the frontispiece of *The Fourth Dimension* (fig. 3). By memorizing the relative positions

11. Casius J. Keyser, “Mathematical Emancipations: The Passing of the Point and the Number Three: Dimensionality and Hyperspace,” *Monist* 16 (1906): 83.

12. Henry Parker Manning, *Geometry of Four Dimensions* (1914; reprint, New York: Dover Publications, 1956), pp. 15–16.

13. Charles Howard Hinton, *A New Era of Thought* (London: Swan Sonnenschein, 1888), pp. 6–7. For a summary of Hinton’s ideas and the concept I termed “hyperspace philosophy,” see Henderson, *Fourth Dimension* (above, n. 5), pp. 26–31; see also “Reintroduction” (above, n. 8).

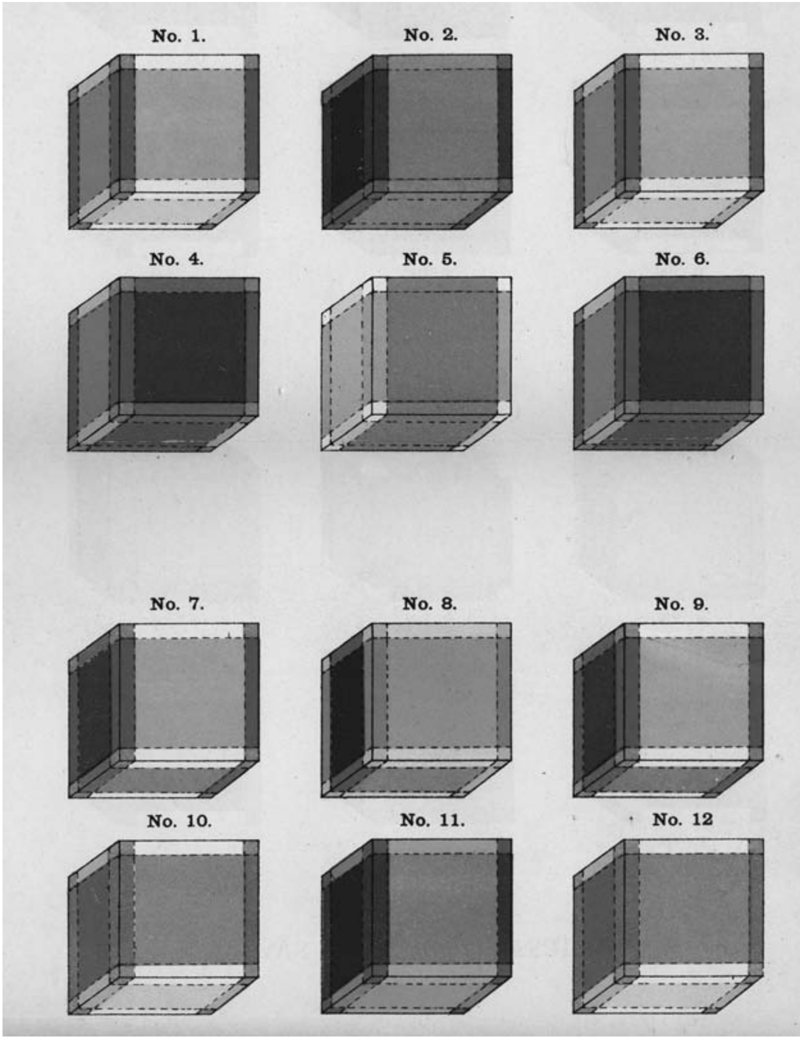


Figure 3. Frontispiece from Charles Howard Hinton, *The Fourth Dimension* (London, 1904).

and color gradations of cubes within large blocks, Hinton's readers were to develop their mental powers and transcend self-oriented perception (e.g., the senses of left/right and up/down or gravity).[14] With this knowledge, they would also be able to visualize the passage of the successive cubic sections of a four-dimensional hypercube through

14. See Charles Howard Hinton, *The Fourth Dimension* (London: Swan Sonnenschein, 1904).

three-dimensional space. But this training was simply the practical prelude to what Hinton hoped would be "a new era of thought," as he declared in that book of 1888: "I shall bring forward a complete system of four-dimensional thought—mechanics, science, art. The necessary condition is, that the mind acquire the power of using four-dimensional space as it now does three-dimensional." Although Hinton never realized such a "system," he extended his ideas into the realm of literature, writing a series of "scientific romances" published in 1884–1885 and 1896.[15]

Although Hinton achieved little personal success or recognition in his lifetime, his writings—with their message of a higher truth and the possibility of self-realization—were remarkably influential in the United States and Europe as well as in England. *The Fourth Dimension*, for example, was reprinted in London five times, in 1906, 1912, 1921, 1934, and 1951. Those who subsequently built upon and/or promulgated his ideas included Bragdon in the United States, mathematician and mystic Peter Demianovich Ouspensky in Russia, German theosophist/anthroposophist Rudolf Steiner in Germany, both mathematicians E. Jouffret and Maurice Boucher and theosophists in France, the symbolist writer Maurice Maeterlinck in Belgium, and theosophist C. W. Leadbeater in England.[16] Ouspensky developed a mystical interpretation of the fourth dimension, associating it with infinity and the achievement of "cosmic consciousness" of a truer, four-dimensional reality.[17] If Ouspensky was envisioning a liberating effect quite different from Hinton's more pragmatic approach, the theme of the fourth dimension as a liberating agent of some kind ran through most all of its interpretations. As Bertrand Russell wrote in his review of *The Fourth Dimension* in *Mind* in October 1904:

> The merit of speculations on the fourth dimension—a merit which the present work possesses in full measure—is chiefly that they stimulate the imagination, and free the intellect from the shackles of the actual. A complete intellectual

15. For the "system" quote, see Hinton, *New Era* (above, n. 13), pp. 86–87. On Hinton's *Scientific Romances*, which were issued by his publisher Swan Sonnenschein in London, see Bruce Clarke's highly insightful discussions of Hinton, idealist philosophy, thermodynamics, and the ether in *Energy Forms: Allegory and Science in the Era of Classical Thermodynamics* (Ann Arbor: University of Michigan Press, 2001), pp. 28–30, 111–121, 175–178.

16. See Henderson, "Reintroduction" (above, n. 8), for this publishing history and a discussion of the impact of Hinton's writings as greater than I had realized in 1983.

17. See P. D. Ouspensky, *Tertium Organum: The Third Canon of Thought, a Key to the Engimas of the World*, trans. Claude Bragdon and Nicholas Bessaraboff (New York: Alfred A. Knopf, 1922).

> liberty would only be attained by a mind which could think as easily of the non-existent as of the existent.[18]

Writers such as Hinton and Bragdon, in particular, had a major impact on the way the public imagined and imaged the fourth dimension during the twentieth century. Painters were particularly responsive to the idea, and many of the stylistic innovations in the first decades of the century were made in the context of attempts to represent or signify in some way the elusive fourth dimension. Russell's reference to the "shackles of the actual" is especially telling, because it points up the fundamental shift that the possibility of a spatial fourth dimension produced in the visual arts. For artists, whose visual imaginations had been largely constrained by painting's traditional allegiance to the visible world, the possibility that space was actually four-dimensional was revolutionary. The chiaroscuro modeling techniques and one-point linear perspective painters had relied upon since the Renaissance to create convincing three-dimensional form and space were irrelevant if the world had four dimensions. One of the pioneers of totally abstract art, the Russian suprematist painter Kazimir Malevich, was encouraged by his belief in four-dimensional space to leave behind completely all traces of the visible world, as discussed below.

There was another strong impetus for breaking the "shackles of the actual" in the late nineteenth- and early twentieth centuries: the discovery of the X-ray by Wilhelm Röntgen in 1895. X-rays proved definitively the limited nature of human vision, which perceives only the narrow band of visible light in the electromagnetic spectrum then being identified.[19] With an impact second only to that of the atomic bomb, the discovery of the X-ray undoubtedly contributed to the continued popular interest in the fourth dimension, which might otherwise have remained the province of mathematicians, philosophers, and mystics.[20] Once the X-ray established the inadequacy of the human eye, however, who could deny with certainty the possibility of a fourth spatial dimension simply because it was invisible?

18. Bertrand Russell, "New Books. *The Fourth Dimension*. By Charles Howard Hinton," *Mind* 13 (1904): 573–574.

19. For this science, including X-rays, see Henderson, "Editor's Introduction: II. Cubism, Futurism, and Ether Physics in the Early Twentieth Century," *Science in Context* 17 (2004): 445–466.

20. For the measure of the impact of the X-ray, see Lawrence Badash, *Radioactivity in America: Growth and Decay of a Science* (Baltimore: Johns Hopkins University Press, 1979), p. 9.

In addition to the fourth dimension and the X-ray, the successive discoveries during the 1890s of the electron and of radioactivity, as well as the interest in the Hertzian waves of wireless telegraphy, contributed further to a radical reconception of the nature of matter and space in this period. [21] Beyond its possible four-dimensionality, matter was transparent to the X-ray and, on the model of radioactivity, was often discussed as dematerializing into the space around it. Moreover, during this period, that space was never thought of as empty; instead, it was understood to be filled with the impalpable ether of space traversed by various ranges of vibrating waves, and the ether itself was thought by some to be the source of matter, as in the "electric theory of matter."[22] Widely popularized, these new scientific discoveries, along with the possibility of a fourth spatial dimension, strongly suggested that an invisible reality existed just beyond the reach of human perception. And in the view of artists and critics, it was the sensitive artist possessed of intuition and imagination—the successor to the visionary seer posited by the symbolists during the 1890s—who would be required to evoke higher dimensions, as well as the newly fluid conceptions of matter and space.

This essay samples the techniques employed in three of the major artistic responses to the fourth dimension during the early twentieth century: cubism, suprematist abstraction, and the art of Marcel Duchamp, the early twentieth-century artist who engaged the fourth dimension most fully, albeit playfully. Only toward the end of the twentieth century would the advent of computer graphics make it possible for artists and geometers to navigate four-dimensional space with mathematical tools, but here also, artistic intuition and imagination would play an important role. After briefly surveying the cultural understanding of the term "fourth dimension" at mid-century, when Einsteinian space-time dominated the layman's awareness of the concept, the essay concludes with a look at the computer-era work of artist Tony Robbin, as well as his collaboration with mathematician Scott Carter to explore the visual properties of braided surfaces and lattices in four and five dimensions.

21. See again, for example, Henderson, "Editor's Introduction: II" (above, n. 19); and Linda Dalrymple Henderson, "Modernism and Science," in *Modernism*, ed. Astradur Eysteinsson and Vivian Liska (Amsterdam: John Benjamins Publishing, 2007), pp. 383–403.

22. See, for example, Oliver Lodge, "Electric Theory of Matter," *Harper's Monthly Magazine* 109 (1904): 383–389.

Cubism: Windows on Invisible Geometrical Complexity

The cubist painter and theorist Jean Metzinger was the first artist to write about the importance of the new geometries for contemporary painters, and he and Juan Gris are said to have studied four-dimensional geometry with the insurance actuary Maurice Princet.[23] All three of these figures were close to Pablo Picasso, who in 1909, along with Georges Braque, developed the style that has come to be known as analytical cubism. While Picasso and Braque drew critical lessons from the art of Paul Cézanne and the conceptual nature of African sculpture, their mature cubism—with its faceted forms and fusion of figure and ground—was a response as well to the exhilarating new ideas about reality issuing from popularized science and mathematics.[24] If Picasso described his goal in cubism as "paint[ing] objects as I think them, not as I see them," the more theoretically oriented Metzinger and the poet Guillaume Apollinaire, another of Picasso's friends, touted the fourth dimension overtly to justify the cubist painter's freedom both to deform objects and to reject perspective. "It is to the fourth dimension alone that we owe a new norm of the perfect," Apollinaire declared in 1912, adding that the concept was part of the "language of the modern studios."[25] In his book *Les Peintre Cubistes* of 1913, the poet likewise dismissed perspective as "that miserable tricky perspective, that fourth dimension in reverse."[26]

In the early 1970s, I suggested that plates from Esprit Pascal Jouffret's 1903 book *Traité élémentaire de géométrie à quatrième dimensions*, such as that shown in figure 4, would have confirmed Picasso's stylistic direction.[27] Since that time, more discussion of Jouffret, Princet,

23. See Herschel Chipp, ed., *Theories of Modern Art: A Source Book by Artists and Critics* (Berkeley: University of California Press, 1968), p. 223n1. Apart from Duchamp, Gris was the most mathematically oriented of the cubists; see William Camfield, "Juan Gris and the Golden Section," *Art Bulletin* 47 (1965): 128–134.

24. For a useful introduction to cubism, see Mark Antliff and Patricia Leighten, *Cubism and Culture* (New York: Thames & Hudson, 2001).

25. Guillaume Apollinaire, "La Peinture nouvelle: Notes d'art," *Les Soirées de Paris* 3 (1912): 90–91. Apollinaire slightly reworded his discussion of the fourth dimension in his 1913 *Les Peintres Cubistes*; see note following for the "language of the studios" reference in that context, as well as Henderson, *Fourth Dimension* (above, n. 5), pp. 74–81, where these texts are analyzed. For Picasso's statement, see Ramón Gómez de la Serna, "Completa y verídica historia de Picasso y el cubismo," *Revista de Occidente* 25 (1929): 100.

26. Guillaume Apollinaire, *The Cubist Painters: Aesthetic Meditations*, ed. Robert Motherwell and trans. Lionel Abel, in *The Documents of Modern Art* series (New York: Wittenborn, 1944), p. 30; for his section on the fourth dimension, see p. 12.

27. Linda Dalrymple Henderson, "A New Facet of Cubism: 'The Fourth Dimension' and 'Non-Euclidean Geometry' Reinterpreted," *Art Quarterly* 34 (1971): 410–433; see also

Figure 4. Juan Gris, *Still Life Before and Open Window: Place Ravignan*, 1915, oil on canvas (Philadelphia Museum of Art, The Louise and Walter Arensberg Collection).

and Picasso has occurred, and Tony Robbin in his book *Shadows of Reality: The Fourth Dimension in Relativity, Cubism, and Modern Thought* argues convincingly that certain techniques in Picasso's paintings of this period, especially his 1910 *Portrait of Daniel-Henry Kahnweiler* (Art Institute of Chicago), derive directly from Jouffret's

E[sprit Pascal] Jouffret, *Traité élementaire de géométrie à quatre dimensions* (Paris: Gauthier-Villars, 1903).

innovative drawing techniques.[28] Robbin is particularly interested in the complex, rectangular areas in the head of Kahnweiler, which he compares to several other of Jouffret's illustrations. "The odd way in which spaces are both inside and outside a four-dimensional figure [with its three-dimensional bounding cells] is the subject of both Jouffret's illustration and Picasso's portrait of Kahnweiler," Robbin concludes.[29]

For the purposes of this essay, figure 4 serves effectively to point up the general similarity between cubist paintings, including Gris's *Still Life Before an Open Window: Place Ravignan* (fig. 5) and Jouffret's techniques for presenting complex figures. Here, the geometer's use of transparency, shifting overlays of differing views of an object, and the resulting spatial ambiguity are strikingly similar to Gris's approach. Like other cubists, Gris combines multiple viewpoints, just as Henri Poincaré had suggested in his 1902 book *La Science et l'hypothèse* that a four-dimensional object could be rendered by means of "several perspectives from several points of view." Given the "muscular sensations" accompanying the transition from view to view, Poincaré had concluded: "In this sense we may say the fourth dimension is imaginable."[30] While Gris's view of trees and a building out the window may appear conventional enough (it is actually a distinct blue monochrome), the complex overlay of visual signs on the table—interacting with the wrought iron of the balcony—deny completely the possibility of reading the space or matter as three-dimensional.

In addition, *Still Life Before an Open Window* effectively evokes the newest scientific ideas of matter and wave-filled space. Here, the in-

28. See Tony Robbin, *Shadows of Reality: The Fourth Dimension in Relativity, Cubism, and Modern Thought* (New Haven, CT: Yale University Press, 2006), pp. 30–33. Arthur Miller rightly connects Picasso to Poincaré versus Einstein in *Einstein, Picasso: Space, Time and the Beauty That Causes Havoc* (New York: Basic Books, 2001), but loses sight of Picasso's artistic context, reducing him to Princet's willing geometry student. For further discussion of Miller's book and others, see Linda Dalrymple Henderson, "Four-Dimensional Space or Space-Time?: The Emergence of the Cubism-Relativity Myth in New York in the 1940s," in *The Visual Mind II*, ed. Michele Emmer (Cambridge, MA: MIT Press, 2005), pp. 384–386n16. On the earliest usages of the term "fourth dimension" in Parisian art circles, which was not specifically geometric, see Henderson, "Reintroduction" (above, n. 8).

29. Robbin, *Shadows* (above, n. 28), p. 33.

30. Henri Poincaré, *La Science et l'hypothèse* (Paris: Ernest Flammarion, 1902), pp. 89–90. On the debt of Metzinger and his fellow artist-author Albert Gleizes to Poincaré's ideas on tactile and motor sensations, including his assertion that "[m]otor space would have as many dimensions as we have muscles," see Henderson, *Fourth Dimension* (above, n. 5), pp. 81–85.

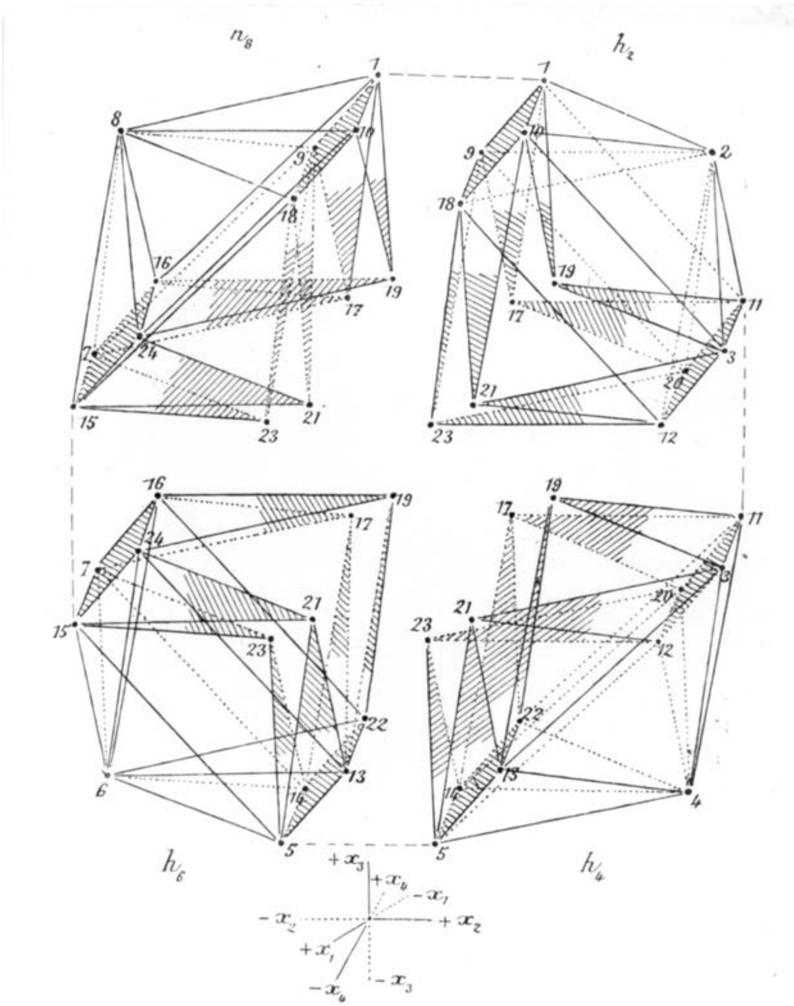


Fig. 41. — Perspective cavalière des seize octaèdres fondamentaux.

Figure 5. "*Perspective cavalière* of the sixteen fundamental octahedrons of the ikosatetrahedroid." (Source: E. Jouffret, *Traité élémentaire de géométrie à quatre dimensions* [Paris, 1903], fig. 41).

terior and exterior of objects and of the room itself interpenetrate, producing the kind of clairvoyant, see-through vision of three-dimensional forms that would be accessible to four-dimensional sight or an X-ray. Not only are spatial clues ambiguous, but Gris plays one kind of light off another, drawing on both visible and invisible light. The mauve and green palette in the central area of the still life contrasts markedly with the ultraviolet or "black light" that seems to illuminate the blue/black areas around the center. Although the bright, seemingly natural light in the central area does not cast shadows or give substance to the objects of the still life, it does refract and distort the *Le Journal* banner line dramatically. Only the curtained window in the upper left corner is painted conventionally in light and shade. However, it is dwarfed by the other ranges of light in the painting, which thus makes a powerful commentary on the changed status of the window as source of visible light and, metaphorically, truth. Gris's *Still Life* and other cubist paintings are testaments to the new paradigm of reality ushered in by the discovery of X-rays and interest in the fourth dimension. Such paintings are new kinds of "windows"—in this case, into a complex, invisible reality or higher dimensional world as imagined by the artist.

My 1983 book *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* was written before I had studied the late-Victorian ether physics still prevalent during the early twentieth century. In the 1980s—and actually from the 1940s onward—the science with which cubism was associated in art historical literature was Einsteinian relativity theory. That conflation was the result of a kind of "short circuit" in the 1940s when discussions of cubist references to the fourth dimension were erroneously linked to the only fourth dimension the public knew—namely, the space-time world of Einstein.[31] But such debates over the supposed relationship of Picasso to Einstein also served to occlude study of the science to which Picasso, Gris, and others were responding in pre–World War I Paris. The recovery of that science has been critical to a fuller history of the impact of the spatial fourth dimension, because the concept was rarely understood in isolation from contemporary ideas about space and matter; instead, it was regularly discussed against the backdrop of contemporary ether physics, beginning with Hinton, who focused attention on the fourth dimension's possible relation to the ether itself.[32]

A case in point is the 1903 book by Maurice Boucher, *Essai sur l'hyperespace: Le Temps, la matière et l'énergie*, which Metzinger men-

31. See Henderson, "Four-Dimensional Space or Space-Time?" (above, n. 28), for the rise of the cubism–relativity myth. For a sampling of articles written on the supposed cubism–relativity connection, see Henderson, *Fourth Dimension* (above, n. 5), appendix A.

32. On this subject, see Henderson, "Editor's Introduction: II" (above, n. 19), and "Modernism and Science" (above, n. 21); see also Henderson, "Reintroduction" (above, n. 8), which addresses Balfour Stewart and P. G. Tait's *The Unseen Universe* (1875), the first source to link the ether to the fourth dimension.

tions in his memoirs. There, Boucher argues in support of the fourth dimension: "Our senses, on the whole, give us only deformed images of real phenomena, some of which have long remained unknown, because none of our organs put us in direct contact with them."[33] As we shall see, the Russian avant-garde knew Boucher's book, as did, quite certainly, Duchamp. Such a text makes clear the close connections of interpretations of the fourth dimension to a contemporary science that, while it dealt with invisible phenomena like the X-ray and the ether, was highly suggestive to the visual imaginations of artists.

Kazimir Malevich's Suprematism: Sections Afloat in Infinite Space

If the cubists created geometrically complex images that suggested the invisible reality beyond surface appearances, the abstract suprematism of Kazimir Malevich utilized the method of sectioning to create geometrical planes moving in space.[34] The two-dimensional analogy that lay behind *Flatland* and was illustrated in Bragdon's *Primer of Higher Space* (fig. 2) had first been discussed extensively by Hinton, and both Ouspensky—Hinton's Russian disciple—and Boucher in his *Essai sur l'hyperespace* followed Hinton's model. That Malevich and his friend, musician and artist Mikhail Matyushin, knew Boucher's *Essai*, with its unification of the fourth dimension and ether physics, is clear from a 1916 text by Matyushin in which he writes: "How to solve the question of 'space,' 'where' and 'where to'? Lobachevsky, Riemann, Poincaré, Bouché, Hinton and Minkovsky provided the answer."[35] In addition to Boucher, Poincaré, Hinton, and Minkowski, Matyushin here cites the two major pioneers of non-Euclidean geometries, Nikolai Ivanovich Lobachevsky and Georg Friedrich Bernhard Riemann.

33. Maurice Boucher, *Essai sur l'hyperespace: Le Temps, la matière, et l'énergie* (Paris: Félix Alcan, 1903), p. 64; see also Jean Metzinger, *Le Cubisme était né* (Chambéry: Editions Présence, 1972), p. 43.

34. For a fuller discussion of the Russian avant-garde and the fourth dimension, see Henderson, *Fourth Dimension* (above, n. 5), chap. 5; for an excellent study of Malevich's art, see Charlotte Douglas, *Kazimir Malevich* (New York: Harry N. Abrams, 1994).

35. M. Matyushin, as quoted in Larissa A. Zhadova, *Malevich: Suprematism and Revolution in Russian Art 1910–1930* (London: Thames & Hudson, 1982), p. 32. In Ouspensky's 1914 revised edition of *Tertium Organum*, the Russians would have heard briefly about Minkowski's four-dimensional space-time continuum, since Ouspensky quoted from a 1911 lecture by physicist N. A. Umov on the subject. However, Ouspensky also critiqued Umov for failing to embrace his belief that time and motion were illusions that would fade away with the advent of higher-dimensional consciousness; see Ouspensky, *Tertium Organum* (above, n. 17), chap. 11.

Matyushin, however, does not include in this list the figure who was even more central to Malevich's invention of suprematism: Ouspensky, the primary Russian advocate of the fourth dimension. By 1916, in fact, Malevich's and Matyushin's enthusiasm for Ouspensky had cooled somewhat, since, in the 1914 edition of his 1911 *Tertium Organum*, Ouspensky had criticized contemporary Russian artists for what he considered their wrong-headed approach to the fourth dimension. Nonetheless, Ouspensky's books, *The Fourth Dimension* of 1909 and *Tertium Organum: A Key to the Enigmas of the World* of 1911, which provided a full accounting of Hinton's ideas, were critical sources for Malevich and his colleagues Matyushin and the poet Alexei Kruchenykh.[36] Most important for Malevich's mature suprematism, however, was Ouspensky's discussion of the transition to four-dimensional "cosmic consciousness" and its relation to infinity. Indeed, Boucher's chapter on infinity and the fourth dimension, as well as his dismissal of the visible world of the senses as illusion, may have been a stimulus for Ouspensky himself—as well as for Malevich.

When Malevich exhibited his first suprematist canvases at the *0.10* exhibition in St. Petersburg in December 1915, one canvas was titled *Movement of Painterly Masses in the Fourth Dimension*, and others bore the subtitles *Color Masses in the Fourth Dimension* and *Color Masses in the Second Dimension* (fig. 6). Malevich's suprematist paintings with planes of one color only strongly suggest the two-dimensional sections or traces created when three-dimensional objects pass through a plane, as discussed in Hinton and Ouspensky and illustrated in Bragdon's *Primer of Higher Space*. These "color masses in the second dimension" may have served Malevich as indirect signs of the fourth dimension by means of the well-known two-dimensional analogy.

Malevich's *Painterly Realism of a Football Player: Color Masses in the Fourth Dimension* (fig. 7), however, is more typical of his suprematist works, which generally include multicolored overlapping planes that prevent a reading of the image as two-dimensional. Here, the artist evokes higher dimensions more directly by suggesting motion through an infinite, multidimensional white space. Eschewing three-dimensional form, Malevich sets two-dimensional planes of high-keyed color into motion, drawing on the theme of time and motion as provisional means of gaining higher spatial understanding. Both

36. For an overview of Ouspensky's philosophy, see Henderson, *Fourth Dimension* (above, n. 5), pp. 245–255. Initially, his advocacy of the practice of alogical logic in order to achieve higher, four-dimensional consciousness had supported Kruchenykh's creation of his transrational *zaum* language in 1913 and Malevich's alogist style of painting during 1913–1914; see ibid., pp. 269–279.

Figure 6. "Futurist Exhibition: 0.10" (contemporary photograph from unidentified source).

Hinton and Ouspensky understood time as a means toward a spatial end, as in its role in both the generation of high-dimensional forms (fig. 1) and their sectioning (fig. 2).[37] Undoubtedly reflecting ideas he shared with Malevich, Matyushin wrote in his diary in May 1915: "Only in motion does vastness reside. . . . When at last we shall rush rapidly past objectness we shall probably see the totality of the whole world."[38]

According to Ouspensky, a "sensation of infinity" and vastness would characterize the first moments of the transition to the new "cosmic consciousness" of four-dimensionality, and Malevich referred specifically to the space of his suprematist paintings as the "white, free chasm, infinity."[39] Fascinated by flight, Malevich does not, however, paint his space blue; instead, it is a cosmic white ex-

37. Hinton wrote: "All attempts to visualize a fourth dimension are futile. It must be connected with a time experience in three space" (ibid., p. 207). For Ouspensky's discussion of this issue, see *Tertium Organum* (above, n. 17), chap. 4.

38. Matyushin diary entry, May 29, 1915; see Henderson, *Fourth Dimension* (above, n. 5), p. 284n173.

39. Malevich, "Non-Objective Creation and Suprematism" (1919), in *K. S. Malevich: Essays on Art 1915–1933*, 2 vols., ed. Troels Andersen (Copenhagen: Borgen, 1971), p. 1:122. For Ouspensky's discussion on infinity and cosmic consciousness, see *Tertium Organum* (above, n. 17), chap. 20.

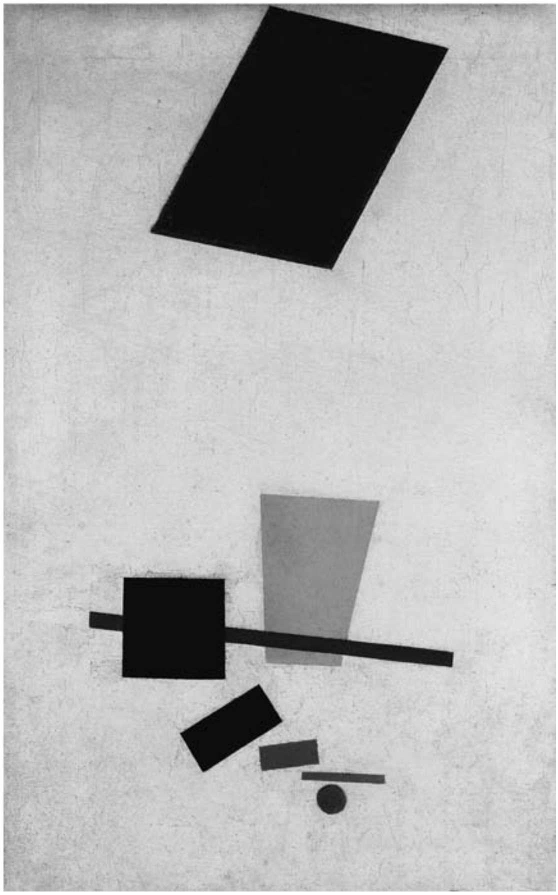


Figure 7. Kazimir Malevich, *Painterly Realism of a Football Player: Color Masses in the Fourth Dimension*, 1915, oil on canvas (estate of the artist).

panse in which variously colored elements float freely, without any specific left/right or up/down orientation, just as Hinton had argued that gaining independence from conventional orientation and the pull of gravity would be the initial step in educating one's "space sense" to perceive the fourth dimension. Like a cubist painter, Malevich generally avoided any signs of the third dimension. However, in contrast to cubism's geometrical complexity and suggestion of a window onto an invisible world, Malevich sought to convey the physiological *experience* of four-dimensional cosmic consciousness, relying on concepts long associated with the fourth dimension: spatial vastness and infinity, freedom from gravity and specific orientation, and implied motion.

Marcel Duchamp: Playful Geometry and Other Signs of the Fourth Dimension

Marcel Duchamp, who had begun his painting career in the context of cubism, was dedicated to realizing aspects of four-dimensional space in his art, but both his approach and his result were far removed from cubism and from Malevich's suprematism. Duchamp's nine-foot-tall work on glass, *The Bride Stripped Bare by Her Bachelors, Even* (1915–1923), known as *The Large Glass* (fig. 8), is a mathematical/scientific allegory of sexual quest, in which Duchamp worked to create an unbridgeable gap between the four-dimensional realm of the biomechanical Bride above and the three-dimensional Bachelor Machine below.[40] His sources on the fourth dimension included Matyushin's entire list of names, quoted earlier, with the substitution of Jouffret for "Minkovsky." But he also read many other sources, since he actually gave up painting for a time and took a job at the Bibliothèque Ste. Genèviève in 1912, determined as he was to "put painting at the service of the mind."[41] Disgusted by what he believed was the mindless, "retinal" painting of his fellow artists, Duchamp found in the fourth dimension a topic tied closely to mental activity, including imagination, intuition, and reason (the latter a prominent theme in Boucher's book), and thus a field in which he could define himself as a new kind of artist. Not only did he trade canvas and oil paint for glass and unconventional materials, such as lead wire, lead foil, and dust, but he developed the *Large Glass* as a text/image project, writing hundreds of preparatory notes that he considered to be as important as the object itself.[42]

40. The discussion of the *Large Glass* that follows is drawn from Linda Dalrymple Henderson, *Duchamp in Context: Science and Technology in the Large Glass and Related Works* (Princeton, NJ: Princeton University Press, 1998); for an overview, see Henderson, "The *Large Glass* Seen Anew: Reflections of Contemporary Science and Technology in Marcel Duchamp's 'Hilarious Picture,'" *Leonardo* 32:2 (1999): 113–126. Duchamp's engagement with the fourth dimension (sans science) is the topic of a chapter in Henderson, *Fourth Dimension* (above, n. 5). The best general introduction to the artist is Dawn Ades, Neil Cox, and David Hopkins, *Marcel Duchamp* (London: Thames & Hudson, 1999).

41. Duchamp, as quoted in James Johnson Sweeney's 1946 interview, *Bulletin of the Museum of Modern Art*; reprinted in *The Writings of Marcel Duchamp*, ed. Michel Sanouillet and Elmer Peterson (1973; reprint, New York: Da Capo Press, 1988), p. 125.

42. For Duchamp's rejection of "retinal" art in favor of "gray matter," see James Johnson Sweeney's 1956 NBC television interview with Duchamp, reprinted in ibid., p. 136. For Duchamp's notes published during his lifetime, see ibid.; for the preparatory notes discovered after his death, see *Marcel Duchamp: Notes*, ed. and trans. Paul Matisse (Boston: G. K. Hall, 1983). These unpublished notes are particularly rich in scientific content and are analyzed in detail in Henderson, *Duchamp in Context* (above, n. 40).

Figure 8. Marcel Duchamp, *The Bride Stripped Bare by Her Bachelors, Even (The Large Glass)*, 1915–23 (Philadelphia Museum of Art, Bequest of Katherine S. Dreier. Copyright © 2010 Artists Rights Society [ARS], New York/ADAGP, Paris/Succession Estate of Marcel Duchamp).

Without Duchamp's notes, we would be hard pressed to decipher the basic narrative of *The Bride Stripped Bare by Her Bachelors, Even*, as well as to appreciate the "playful physics" and geometry that underlie it. Basically, a series of operations begins at the left side of the Bachelors' realm during which "illuminating gas" is gradually liquefied into a semen-like "erotic liquid," which is ultimately splashed onto the upper half to form the chance-determined "Nine Shots" at the right of the Bride's realm. This is the closest the Bachelors come to making contact with the object of their desire. In order to establish insurmountable allegorical "collisions" between the desiring Bachelors and the unreachable Bride, Duchamp drew on contemporary science as well as the four-to-three-dimensional contrast between their realms.[43] Boucher's *Essai sur l'hyperespace* would have been an especially relevant source for him, since it treated the fourth dimension in relation to contemporary ideas on matter, energy, and the ether. In fact, wave-borne communication is a central theme of the *Large Glass*, in which the Bride, hanging gravity-free in her etherial, four-dimensional realm, issues commands to the Bachelors by means of her "splendid vibrations." The Bride's basic columnar form is rooted in X-ray images, and her vibratory communications are based on the latest wireless telegraphy and radio control via the ether. By contrast, the laws of classical mechanics, playfully "stretched" by Duchamp, rule the lower half of the work, where the Bachelors are further constrained by perspective and the relentless pull of gravity.[44]

Although Duchamp never published the comprehensive text he originally envisioned to accompany the *Large Glass*, his boxes of facsimiles of his notes, primarily *The Green Box* of 1934 and *A l'infinitif (The White Box)* of 1966, testify to the breadth of his study and his powers of verbal invention in creating his "hilarious picture."[45] Given the fate of the spatial fourth dimension in the wake of Einstein's emergence in the 1920s, Duchamp chose not to include his notes on the fourth dimension in the *Green Box*. But by the 1960s, the subject was beginning to reemerge in culture, and his *White Box* notes on the subject display his rich imagination and wit as he played with the laws of four-dimensional geometry and explored other means by which he might make the Bride's realm four-dimensional. Duchamp's notes and drawings offer highly inventive approaches to the topic, which, in the end, were unrealizable; nonetheless, his verbal invention in the notes stands as a significant counterpart to the *Large Glass* itself.

Duchamp speculated extensively on four-dimensional geometry, working by means of analogy and developing his own playful laws

43. On the *Large Glass* and allegory, see Linda Dalrymple Henderson, "Etherial Bride and Mechanical Bachelors: Science and Allegory in Marcel Duchamp's 'Large Glass,'" *Configurations* 4 (1996): 91–120, and *Duchamp in Context* (above, n. 40), chap. 12.

44. For "splendid vibrations," see Duchamp, *The Green Box*, in *Writings* (above, n. 41), p. 42; for these aspects of the *Large Glass*, see Henderson, "The *Large Glass* Seen Anew" (above, n. 40).

45. For "hilarious picture," see Duchamp, *The Green Box*, in *Writings* (above, n. 41), p. 30.

on the subject.[46] Although he considered Poincaré's ideas on geometrical continua and cuts as well as the use of mirrors and virtual images as possible signs of the Bride's four-dimensionality, he finally returned to the notion of shadows, as articulated by Jouffret: "The *shadow* cast by a 4-dim'l figure on our space is a *3-dim'l* shadow."[47] Thus Duchamp painted the Bride to resemble a photograph of a three-dimensional figure, whom he thought of as the shadow of the true, four-dimensional Bride. However, he also took additional steps to augment the Bride's four-dimensional otherness, creating for her a spatial realm he defined as beyond measure (in contrast to the Bachelor's "mensurable" and "imperfect" forms).[48] In her infinite, immeasurable realm, the Bride, described as free of gravity, suggests qualities associated with expanded spatial perception in the tradition of Hinton. Yet Duchamp was far from Ouspensky's and Malevich's pursuit of mystical "cosmic consciousness"; instead, the self-proclaimed Cartesian was much closer to Boucher, the advocate of reason, in approaching the fourth dimension.[49]

Duchamp abandoned the execution of the *Large Glass* in 1923, leaving it unfinished and missing several components. Although he never added the Juggler or Handler of Gravity to the work itself, this key intermediary figure was to have stood symmetrically opposite the Bride, and to have facilitated communication between the Bride and the Bachelors.[50] Drawn in the form of a spiral, the Juggler would have been able to function in both three and four dimensions, thus evoking the dimension-transcending associations of the spiral, which Hinton had utilized to demonstrate the illusion of a circling point created as a spiral passed through a plane.[51] The spiral

46. See Duchamp, *A l'infinitif*, in ibid., pp. 84–101. For an overview of these notes, see Henderson, *Fourth Dimension* (above, n. 5), chap. 3. Craig Adcock has made the most extensive study of these particular notes, in *Marcel Duchamp's Notes from the "Large Glass": An N-Dimensional Analysis* (Ann Arbor, MI: UMI Research Press, 1983).

47. Duchamp, *A l'infinitif*, in *Writings* (above, n. 41), p. 89. The note continues: "(see Jouffret, Géom. à 4 dim., page 186, last 3 lines.)."

48. Duchamp, *The Green Box*, in ibid., pp. 44–45.

49. On Duchamp's embrace of "logic and close mathematical thinking," which he associated with Cartesianism, see Henderson, *Duchamp in Context* (above, n. 40), pp. 77, 269n59; for Boucher's advocacy of reason, see, for example, Boucher, *Essai* (above, n. 33), pp. 144, 170.

50. For the Juggler, see Duchamp, *The Green Box*, in *Writings* (above, n. 41), p. 65; for Jean Suquet's drawing that superimposes the Juggler onto the *Large Glass*, see Henderson, "Etherial Bride" (above, n. 43), as well as *Duchamp in Context* (above, n. 40), fig. 111.

51. See Hinton, *Fourth Dimension* (above, n. 14), p. 27; and Henderson, *Fourth Dimension* (above, n. 5), fig. 32.

had a second link to the fourth dimension: advocates of a higher dimension pointed to right- and left-handed spiral growth in nature as "scientific" evidence for the existence of four-dimensional space. Such mirror symmetrical pairs, which also included right and left hands and right- and left-handed growing crystals as well as spirals, would need to be turned through a fourth dimension to be made to coincide with their opposites. Mirrors themselves were also prevalent in popular literature on the fourth dimension from the start, including the mathematician Lewis Carroll's *Through the Looking Glass* of 1872.[52] Duchamp utilized mirror silver on the surface of the *Large Glass* to create the "Oculist Witnesses" (the circular eye chart–like forms at the right of the Bachelors' realm), who were to "dazzle" upward a mirror reflection of the orgasmic splash to produce the Nine Shots. He had already played with the notion of mirror reversals and hinges in his hinged, semi-circular glass panel *Glider Containing a Watermill* of 1913 (Philadelphia Museum of Art), which offers the viewer mirror-reversed images of its front and back.

During the 1920s and '30s, Duchamp combined his interest in the spiral with movement, setting spiraling disks into motion so that they seemed to pulsate outward and inward. These experiments in optics would subsequently link Duchamp, the early twentieth century's most committed student of the spatial fourth dimension, to the kinetic art that developed during the early 1920s in response to the new focus on time in Einsteinian relativity theory. The Hungarian artist László Moholy-Nagy was the primary advocate of the new space-time kinetic art, which he promulgated in books such as his *Von Material zu Architektur* (subsequently translated as *The New Vision*) of 1928 and *Vision in Motion* of 1947.[53] By the later 1940s and '50s, Duchamp was regularly grouped with Moholy-Nagy and Alexander Calder as a kinetic artist. Yet he had not forgotten the spatial fourth dimension that had been so central to the *Large Glass*, and in 1957, the artist and his wife Teeny were reading Kasner and Newman's *Mathematics and the Imagination*, which was in its fourteenth edition.[54] Duchamp must have been delighted by the au-

52. On spirals or mirrors and the fourth dimension, see Henderson, *Fourth Dimension* (above, n. 5), index; on Lewis Carroll, pseudonym of mathematician Charles Dodgson, see ibid., pp. 21–22.

53. On this development as well as on Moholy-Nagy, see Linda Dalrymple Henderson, "Einstein and 20th-Century Art: A Romance of Many Dimensions," in *Einstein for the 21st Century: His Legacy in Science, Art, and Modern Culture,* ed. Peter L. Galison, Gerald Holton, and Silvan S. Schweber (Princeton, NJ: Princeton University Press, 2007), pp. 101–129.

54. Jacqueline Monnier (Duchamp's stepdaughter), letter to author, July 20, 2001.

thors' praise for the spatial fourth dimension (no "greater forward step"), as quoted earlier. And with stirrings of renewed interest in the idea during the later 1950s and '60s, including in Martin Gardner's *Scientific American* columns, Duchamp clearly decided that his playful musings on four-dimensional geometry might once again be intelligible and decided to publish them.[55]

Science fiction was one of the contexts in which the spatial fourth dimension had survived, and, recast as the "fifth dimension" (because time was now so widely linked to the fourth dimension), the idea achieved new exposure in fantasy literature (e.g., Madeleine L'Engle's 1962 *A Wrinkle in Time*) and on television, beginning in 1959, in *The Twilight Zone*. There, Rod Serling's memorable introduction touched upon many qualities earlier associated with the fourth dimension, including imagination. "There is a fifth dimension," he intoned,

> beyond that which is known to man. It is a dimension as vast as space and as timeless as infinity. It is the middle ground between light and shadow, between science and superstition, and it lies between the pit of man's fears and the summit of his knowledge. It is the dimension of imagination. It is an area which we call . . . the Twilight Zone.[56]

In his 1962 *Profiles of the Future*, Arthur Clarke recalled of the idea: "The fourth dimension has been out of fashion for quite a while: it was fashionable round the turn of the century, and perhaps it may come back into style some day."[57] That would certainly begin to happen subsequently during the 1960s, in the "space age" Clarke himself had foretold in his writings.

For those artists who turned their attention to the spatial fourth dimension during the second half of the twentieth century, it was often an encounter with literature on the subject from the early years of the century that introduced them to the concept. This was true for Park Place Gallery artist Peter Forakis, who in 1957, while a student at the California School of Fine Arts, found copies of Bragdon's *Frozen Fountain* of 1932 and Ouspensky's *Tertium Organum* at an artist's estate sale. In the age of Einstein, these books were akin to some kind of ancient wisdom that went against the grain of culture at large. During the 1960s, Forakis would go on to explore approaches to the fourth dimension in his geometrically oriented

55. For an "archeology" of the traces of the fourth dimension as they emerged during the 1960s, including Gardner, see Henderson, "Reintroduction" (above, n. 8).

56. See Marc Scott Zicree, *The Twilight Zone Companion* (New York: Bantam Books, 1992), p. 31.

57. Arthur C. Clarke, *Profiles of the Future* (New York: Harper & Row, 1962), p. 78.

sculpture, which also responded to Buckminster Fuller's incorporation of the idea into his "synergetic geometry."[58] Both Duchamp's notes and Fuller's ideas were important for Robert Smithson, for whom the spatial fourth dimension was a central concern during the latter half of the 1960s, and for whom mirrors and spirals were key signifiers of the idea.[59]

Tony Robbin: Four-Dimensional Art Grounded in Mathematics and Physics

The later twentieth-century artist who has actually engaged four-dimensional geometry most fully—in the tradition of Duchamp though seriously, not playfully—is Tony Robbin. Robbin arrived in New York from graduate school at Yale University in 1969, two years after the Park Place Gallery had closed its doors. But in an art world dominated by minimalism and critic Clement Greenberg's dogma of flatness in painting, space, in general, was not a topic of artistic discussion, and he never heard anything of the Park Place artists' interest in the fourth dimension.[60] Robbin's paintings of the early 1970s are considered part of the pattern and decoration movement, but he was particularly interested in the disjunctions between contrasting areas of subtly colored patterns in his works. In a text accompanying Robbin's exhibit at the Whitney Museum of American Art in 1974, curator Marcia Tucker wrote that the "contradictory visual information" in Robbin's paintings "suggests the complexity of four-dimensional geometry."[61] And in a scenario reminiscent of Forakis's find, Robbin made contact with a mathematics professor at Trenton State College where he was teaching, and into his hands came a cache of sources on four-dimensional geometry and space, including early twentieth-century books by H. P. Manning and Duncan Sommerville,

58. See Henderson, "Einstein and 20th-Century Art" (above, n. 53), pp. 124–125; for a fuller discussion of Forakis, see Henderson, "Park Place" (above, n. 3).

59 On Smithson and the fourth dimension, see Henderson, "Reintroduction" (above, n. 8); for a concise version, see Linda Dalrymple Henderson, "Space, Time, and Space-Time: Changing Identities of the Fourth Dimension in 20th-Century Art," in *Measure of Time*, ed. Lucinda Barnes (Berkeley: Berkeley Art Museum and Pacific Film Archive, 2007), pp. 95–99.

60. For Robbin's early work and history, see *Fourfield: Computers, Art, and the Fourth Dimension* (Boston: Bullfinch Press, 1992); on the critical views that militated against artists' interest in space during the later 1960s, see Henderson, "Park Place" (above, n. 3), pp. 35–41.

61. Marcia Tucker, *Tony Robbin* (New York: Whitney Museum of American Art, 1974). Tucker, who knew the Park Place artists, may well have encountered the idea of the spatial fourth dimension there.

as well as Robert Marks's *Space, Time, and the New Mathematics.* Additionally discovering Coxeter's *Regular Polytopes*, Robbin was launched on his trajectory to become the most serious artist-scholar in four-dimensional geometry of the twentieth century.[62]

From that point, Robbin undertook the serious study of four-dimensional geometry, physics, and computer programming that would support his creation of works such as his twenty-seven-foot painting of 1980–1981, *Fourfield* (fig. 9), and the publication of his first book, *Fourfield: Computers, Art, and the Fourth Dimension*, in 1992. In his quest to convey the complexity of four-dimensional space as projected in three dimensions, it was Thomas Banchoff's rendering of the four-dimensional, planar rotations of the hypercube in his 1978 film *The Hypercube: Projections and Slicings* that held the key. Combining his exquisite sense of color with sophisticated mathematical principles, Robbin has created a remarkable body of work over more than thirty years. In *Fourfield*, for example, he painted a richly textural, colored background of Necker-reversing, four- and six-sided figures. To this mutating ground he then added painted lines and three-dimensional rods extending from the canvas surface, representing pairs of isometric projections of the eight bounding cubes of the hypercube in slightly altered positions. As a viewer walks from one end of *Fourfield* to the other, the painted lines and white metal rods, both shadows of the hypercube, shift and mutate, mimicking the distortions that occur in Banchoff's projections of the hypercube's planar rotation in four-dimensional space.[63]

As documented in his book *Fourfield* and his 2006 book *Shadows of Reality*, Robbin has worked over the years in close consultation with a number of mathematicians and physicists. In doing so, he has gained a level of expertise far beyond that of other artists and is recognized for his contributions in mathematics as well as for the engineering applications set forth in his 1996 book *Engineering a New Architecture*.[64] Robbin's art continued to develop in new directions in

62. Tony Robbin, e-mail message to author, October 12, 2003.

63. Banchoff's film, which he showed around the world, accompanying it with lectures, was highly influential in spreading news of the spatial fourth dimension. Robbin discusses his work with Banchoff in *Fourfield* (above, n. 60), and addresses "The Computer Revolution in Four-Dimensional Geometry" in chapter 10 of his *Shadows of Reality* (above, n. 28).

64. *Shadows of Reality* (above, n. 28) contains a passionate argument for the model of projections versus slicing as a way to understand dimensional relationships in mathematics and physics; for example, Robbin makes a close rereading of Minkowski's papers of 1907 and 1908 that interprets the space-time continuum as a geometry of projection, rather than the common interpretation of a slicing of worldliness (chap. 4). His chapter 1 includes an unprecedented history of early techniques for rendering four-dimensional objects.

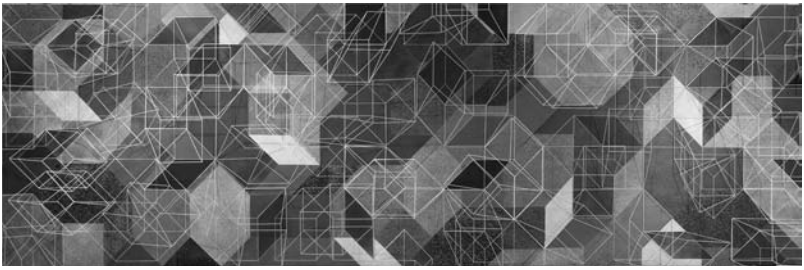


Figure 9. Tony Robbin, *Fourfield*, 1980–81, acrylic on canvas with welded steel rods (courtesy of the artist).

tandem with his explorations in mathematics and physics, including wire sculpture reliefs illuminated by colored light and, subsequently, works grounded in the principles of quasi-crystal geometry. More recently, Robbin has returned to painting in a rich and sensuous palette, combining mathematical structures with painterly execution (fig. 10).[65] Having been in dialogue with topologist Scott Carter for the last several years, he now conceives of these paintings as four-dimensional knot diagrams—with three-dimensional lattices, composed of the polyhedra associated with quasi-crystals, interweaving with one another. Carter has likewise credited his seeing one of Robbin's wire-rod paintings in the 1980s with helping him approach a problem in topology, and the more recent collaborations of the two are supporting Carter's further topological investigations.[66]

As Robbin wrote in 2007, "[t]he artist using mathematical ideas should not merely illustrate them; mathematical models are to art as medical illustrations are to the work of Rembrandt. The goal is to see the higher-dimensional space, to get the feeling of being inside them, and to revel in their liberating possibilities."[67] Thirty years earlier, in 1977, he had declared in an article on "The New Art of 4-Dimensional Space":

65. For the various phases of Robbin's development, see *Fourfield* (above, n. 60) and *Shadows of Reality* (above, n. 28); he recounts his interactions with mathematicians and physicists in both *Fourfield* (numerous sidebars) and *Shadows*. Among the exchanges discussed in the latter work is that with quantum physicist P. K. Aravind, for whom four-dimensional projective geometrical figures have become important to his research on particle entanglement (pp. 85–92).

66. Scott Carter, e-mail message to author, August 3, 2004. According to Carter, "Tony's painting spoke directly to me since I had seen glimpses of 4-space in my own research. He had escaped the plane of the canvas in order to explain escaping the plane of the 3-dimensional world."

67. Tony Robbin, unpublished statement (2007).

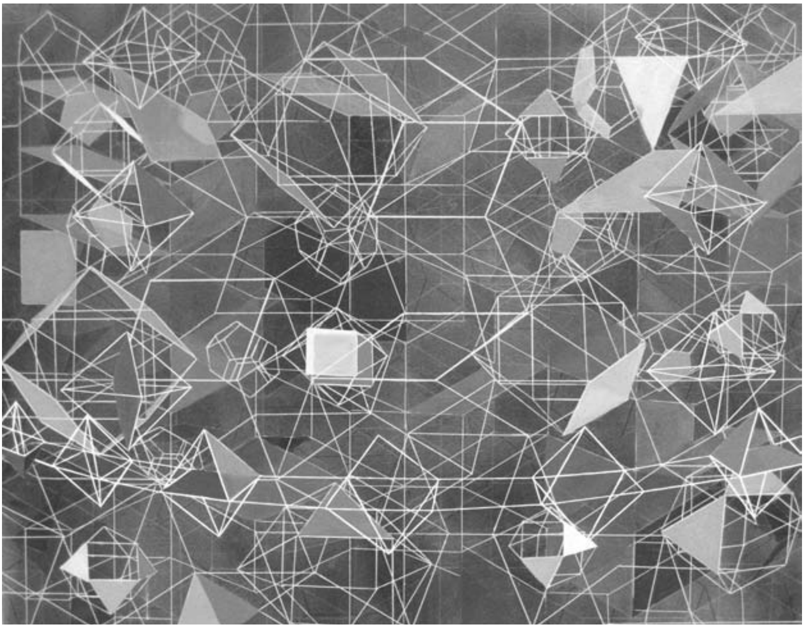


Figure 10. Tony Robbin, *2007-5*, 2007, acrylic on canvas (courtesy of the artist).

> We are not in the least surprised . . . to find physicists and mathematicians working simultaneously on a metaphor for space in which paradoxical three-dimensional experiences are resolved only by a four-dimensional space. Our reading of the history of culture has shown us that in the development of new metaphors for space artists, physicists, and mathematicians are usually in step.[68]

Soon after Robbin wrote this, the field of computer graphics and the personal computer emerged as powerful new tools to stimulate the visual imaginations of mathematicians and artists alike. Yet whether by means of the computer or not, four-dimensional geometry and the multifaceted, popular fourth dimension have served as key sources for artists in the twentieth and now in the twenty-first century. Almost a hundred years ago, Malevich's friend Matyushin pointed to the centrality of space to the activity of the artist: "Artists have always been knights, poets, prophets of space in all eras."[69] The subsequent development of art proved Matyushin himself to be prophetic.

68. Tony Robbin, "The New Art of 4-Dimensional Space: Spatial Complexity in Recent New York Work," *Artscribe* 9 (1977): 20.

69. M. V. Matyushin, "Of the Book by Gleizes and Metzinger, *Du Cubisme*," *Union of Youth* 3 (1913): 25, reprinted in Henderson, *Fourth Dimension* (above, n. 5), appendix C.